The Huygens Probe: Science, Payload and Mission Overview

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The Huygens Probe is the ESA-provided element of the joint NASA/ESA Cassini/Huygens mission to Saturn and Titan. Huygens is designed to descend through the atmosphere of Titan, Saturn's largest moon, to the surface. The prime scientific mission phase occurs during the 2-2.5 h parachute descent. Measurements will also be conducted during the 3 min entry phase and possibly on the surface if Huygens survives impact. The Probe's payload comprises six instruments. This paper provides an overview of the mission and a concise description of the payload as an introduction to the more detailed papers in this volume.

1. Introduction

Huygens is an atmospheric probe designed to study the atmosphere and surface of Titan, the largest moon of Saturn. The objectives are to carry out detailed in situ measurements of the physical properties, chemical composition and dynamics of the atmosphere and local characterisation of the surface. Huygens is a highly sophisticated robotic laboratory equipped with six scientific instruments.

Huygens is the element contributed by ESA to Cassini/Huygens, the joint NASA/ESA dual-craft mission to the Saturnian system. The Cassini spacecraft comprises the NASA-provided Saturn Orbiter and the ESA-supplied Titan Huygens Probe. The overall mission is named after the French/Italian astronomer Jean-Dominique Cassini, who discovered several Saturnian satellites and ring features (the Cassini division) in 1671-1685. The Probe is named after Dutch astronomer Christiaan Huygens, who discovered Titan in 1655.

The mission's primary launch window opens in early October 1997. Launch is scheduled from Cape Canaveral, Florida aboard a Titan 4B/Centaur rocket. After an interplanetary voyage of almost 7 years, the spacecraft will arrive at Saturn in late June 2004, when a manoeuvre will place it in orbit around the planet. The Probe's mission will be executed in November 2004, at the end of the first of the many orbits about Saturn. Following the Huygens mission, the Orbiter will begin its intensive 4-year exploration of the Saturnian system.

The exploration of Titan is at the very heart of the Cassini/Huygens mission. The Orbiter will make repeated targeted close flybys of Titan, gathering data about the moon and making gravity-assist orbit changes that will allow it to make a tour of the satellites, reconnoitre the magnetosphere and obtain views of Saturn's higher latitudes. During its 4-year nominal mission, Cassini will make detailed observations of Saturn's atmosphere, magnetosphere, rings, icy satellites and Titan. The detailed, in situ data set acquired by the Probe and the global data set from the Orbiter's tour will undoubtedly provide a unique wealth of information that will substantially increase our knowledge of Titan, a fascinating planet-sized moon shrouded by a thick, hazy and chemically active atmosphere.

This paper is organised as follows. In section 2, a brief history of the development of the Cassini/Huygens mission is given. In section 3, a mission overview is provided. The scientific objectives of the Huygens Probe are described in section 4. Then, in section 5, the main characteristics of Titan are reviewed, with an emphasis on the 'engineering' knowledge of Titan needed to design the Probe. The main features of the payload are described in section 6. An overview of the Huygens mission is provided in section 7. The accommodation of the payload and the operational constraints are discussed in section 8. The Huygens flight operations are discussed in section 9. A brief overview of the data analysis phase and of the data archive plans is given in section 10.

2. The Mission's Historical Development

The development of such a complex and ambitious venture between NASA and ESA required substantial scientific, technical and programmatic planning efforts over several years. Several scenarios for a mission to Saturn were studied within NASA from the late 1970s as the next natural step on from the Galileo orbiter/probe mission at Jupiter in the detailed exploration of the giant planets.

The Cassini mission, in its present form, was originally proposed to ESA as a collaborative venture with NASA in response to a regular call for mission ideas released by ESA's Directorate of Science. The mission was proposed in November 1982 by a team of European and American scientists lead by D. Gautier and W. Ip. After an initial assessment, it was then subjected to a joint 1-year ESA/NASA assessment study starting in mid-1984 (ESA SCI, 1985; ESA SCI, 1986). Very early in that study phase, the Titan Probe was identified as ESA's potential contribution, within its financial constraints and the technical capabilities of the European space industry. It was subsequently selected by ESA for a competitive Phase A study in 1986, but the start was delayed by a year to allow programmatic adjustment with NASA. Phase A was conducted from November 1987 to September 1988 (ESA SCI, 1988; Lebreton & Scoon, 1988; Lebreton, 1990; Lebreton, 1992; Lebreton & Matson, 1992).

The Titan Probe was selected by ESA's Science Programme Committee in November 1988 as the first medium-size mission ('M1') of the Horizon 2000 long-term space science plan, in competition with four other missions (Vesta, Lyman, Grasp and Quasat). Grasp, which became Integral, was eventually selected in 1994 as the M2 mission. During its selection process, the Titan probe was named Huygens, in honour of the discoverer of Titan. Within NASA, Cassini was part of the CRAF (Comet Rendezvous & Asteroid Flyby)/Cassini programme, which was approved in the 1989 budget.

CRAF/Cassini was subjected to NASA's annual budget exercise and only the development of Cassini went ahead, as CRAF was cancelled by the agency for budgetary reasons in January 1992. As part of the process, the Cassini mission was greatly restructured in early 1992, and the modified Cassini-alone programme was authorised in May 1992. As a result of the restructuring, the two articulated science platforms (Jaffe & Lebreton, 1992) and the articulated dedicated Huygens antenna were deleted. The Orbiter instruments became body-mounted, but several instruments added their own articulation to temper the losses of the platforms. The Huygens receivers were directly interfaced with the Orbiter's main antenna. Huygens was essentially unhurt by the restructuring process. This exercise also studied the possibility of launching the spacecraft in two sections on separate Shuttle missions for on-orbit assembly before dispatching it on its interplanetary journey. This scenario did not prove to be feasible.

Selection of the Orbiter and Probe investigations was subjected to coordinated planning by the two agencies. ESA and NASA released a joint Announcement of Opportunity in October 1989 calling for investigations on the Probe and Orbiter, respectively. Both payloads were selected in close coordination between the two agencies and with the European national agencies that provided funding for specific hardware contributions. The Probe and Orbiter payload selections were announced by ESA and NASA, respectively, in September and November 1990. In addition to hardware investigations, ESA and NASA respectively selected three and seven Interdisciplinary Scientist Investigations.

During the investigation selection process, the Italian Space Agency (ASI) initiated a bilateral collaboration with NASA that provided for significant augmentation of the Orbiter payload capabilities beyond what NASA alone could fund, in areas of prime interest to the Italian scientific community. This bilateral effort also included the provision by ASI of a major Orbiter element: the 4-band (S, X, Ku, Ka) High Gain Antenna (HGA).

During the Phase A study, the need for using gravity assist was identified to inject the spacecraft towards Saturn. Three launch opportunities were identified that included a Jupiter flyby in addition to Venus and Earth flybys. Jupiter is required to reach Saturn in a reasonable time: 6-7 years, instead of 9-10 years. At the time of the joint CRAF/Cassini programme, Cassini was scheduled for launch during the second opportunity, in April 1996. After CRAF's cancellation, the possibility of accelerating the programme and launching in December 1995 was looked at, but the October 1997 launch opportunity was eventually selected as it was the only one of the three compatible with NASA's budget profile for developing the Cassini spacecraft.

3. Overview of the Cassini/Huygens Mission

The Cassini mission is designed to explore the Saturnian system and all its elements: the planet and its atmosphere, its rings, its magnetosphere and a large number of its moons, namely Titan and the icy satellites. The mission will pay special attention to Titan, Saturn's largest moon and the solar system's second largest after Jupiter's Ganymede. Cassini's broad scientific aims are to:

1. determine the dynamical behaviour of Saturn's atmosphere;
2. determine the chemical composition, physical structure and energy balance of Titan's atmosphere;
3. observe the temporal and spatial variability of Titan's clouds and hazes;
4. characterise Titan's surface;
5. determine the structure, composition and geological history of Saturn's icy satellites;
6. study the structure of the rings and the composition of the rings' material;
7. study the structure, chemical composition and global dynamics of Saturn's magnetosphere.

An important aspect of the Cassini mission is the study of the interaction and interrelation of the system's elements. Studying the interrelation between the rings and the icy satellites, and the interaction of the satellites and of Titan's ionosphere with Saturn's magnetosphere is a key objective.

The Cassini/Huygens spacecraft (Fig. 1) is being readied for launch in October 1997 by a Titan 4B/Centaur rocket from Cape Canaveral Air Station in Florida. With a launch mass of 5548 kg, it is too heavy for direct injection to Saturn. Instead, it requires gravity assists from several planets (Fig. 2): Venus (April 1998 and June 1999), Earth (August 1999) and Jupiter (December 2000). This launch opportunity allows Saturn to be reached in about 7 years. There are later opportunities (which add

2 years to the total flight time to Saturn because they do not include a Jupiter flyby) in December 1997 and March 1999, but they are less favourable from the launch performance and science point of views. This is particularly true for the ring science as the solar and Earth-viewing phase angle of the rings would be much less favourable in 2008-2012 than they are in 2004-2008. The maximum ring opening angle occurs in 2002.

The Cassini/Huygens spacecraft will arrive in the vicinity of Saturn in late June 2004. The arrival date has been calculated to allow a flyby of distant moon Phoebe during the approach phase to Saturn. The most critical phase of the mission after launch is Saturn Orbit Insertion (SOI), on 1 July 2004. Not only is it a crucial

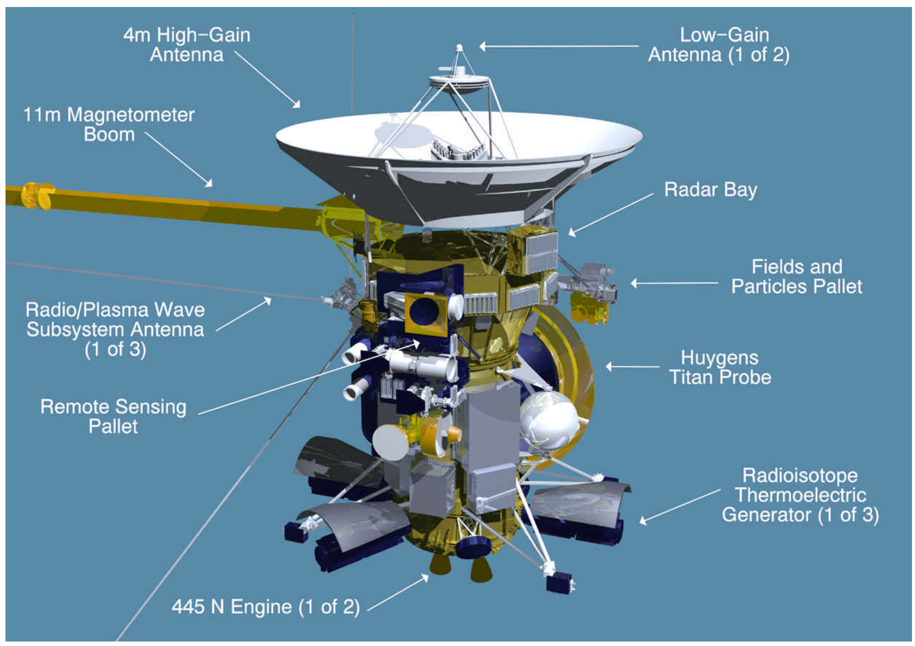


Fig. 1. Principal features of the Cassini-Huygens spacecraft.

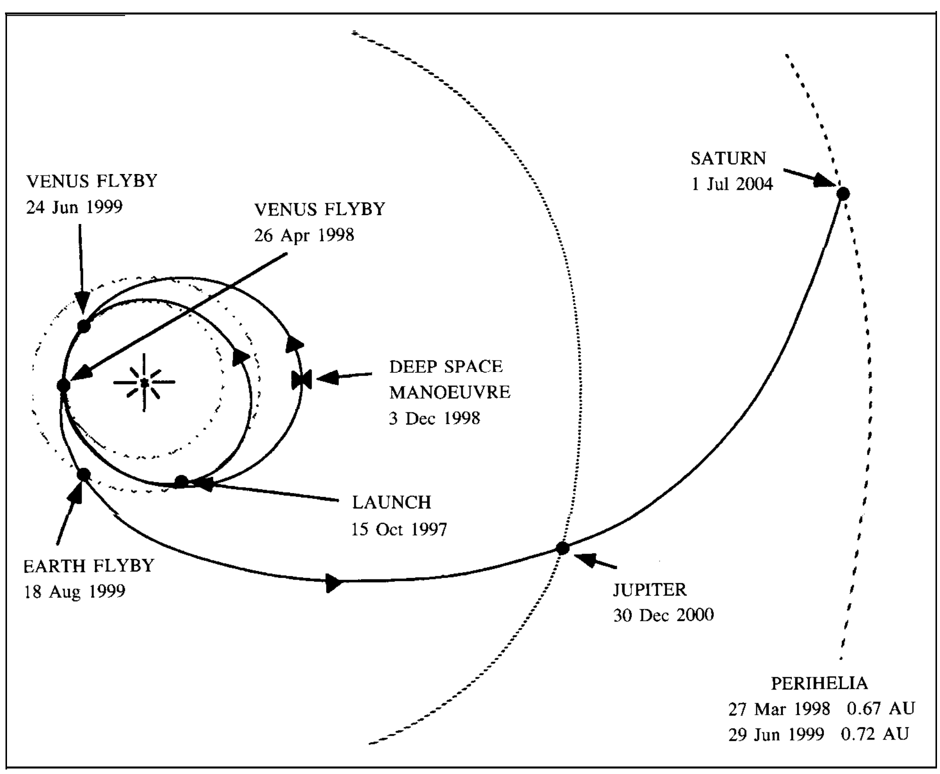


Fig. 2. The Cassini/Huygens interplanetary trajectory. The spacecraft uses four gravity assists because the launcher is not powerful enough to inject it on a direct trajectory to Saturn. The diagram has been modified to reflect the actual launch date.

manoeuvre, but also a period of unique Orbiter science activity as, at that time, the spacecraft is as close as it ever will be to the planet (at 0.3 R_s about 2 h before and 2 h after ring plane crossing). Ring plane crossing occurs in the gap between the F and G rings at a distance of about 2.66 R_s. The SOI part of the trajectory provides a unique observation geometry for the rings.

The Huygens Probe is carried to Titan attached to the Saturn Orbiter (Fig. 3). It is released from the Orbiter on 6 November 2004 after SOI at the end of the initial orbit around Saturn, nominally 22 days before Titan encounter (Fig. 4). Shortly (typically 2 days) after Probe release, the Orbiter will perform a deflection manoeuvre to set up the radio link geometry for the Probe descent phase. This manoeuvre will also set up the initial conditions for the satellite tour after completion of the Probe mission.

Huygens' encounter with Titan is planned for 27 November 2004. The celestial mechanics do not allow much freedom for the arrival date at Saturn. However, the Huygens Titan encounter date, dictated by the duration of the initial orbit around Saturn, is adjustable by multiples of 16 days, which corresponds to Titan's 15.95 day orbital period around its parent.

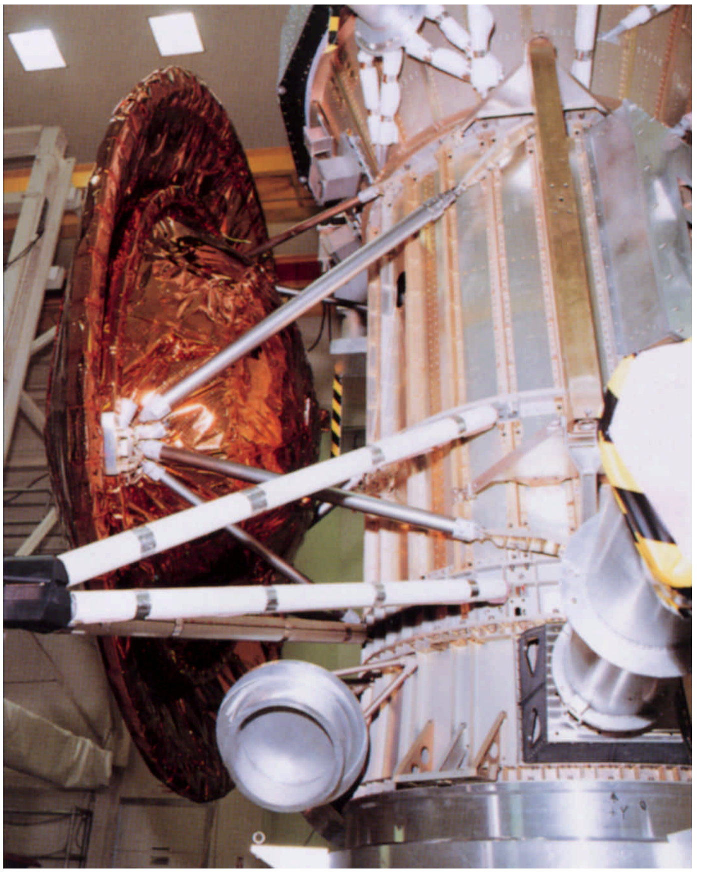


Fig. 3. The Huygens Probe is attached to the Orbiter propulsion module via the spin eject device, below the High Gain Antenna.

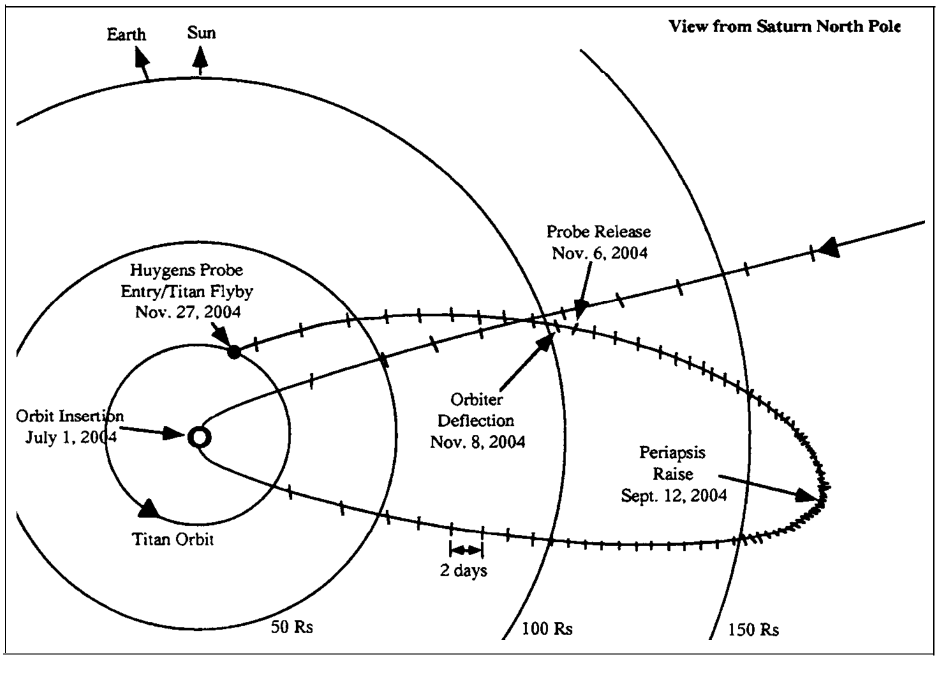


Fig. 4. The Huygens release orbit. Huygens will be released from the Orbiter at the end of the first revolution around Saturn. The second orbit is considered as a backup in case release is somehow prevented during the first.

4. Huygens Scientific Objectives

The scientific objectives of the Cassini/Huygens mission at Titan are to:

1. determine atmospheric composition;
2. investigate energy sources for atmospheric chemistry;
3. study aerosol properties and cloud physics;
4. measure winds and global temperatures;
5. determine properties of the surface and infer internal structure;
6. investigate the upper atmosphere and ionosphere.

Huygens' goals are to make a detailed in situ study of Titan's atmosphere and to characterise the surface of the satellite along the descent ground track and near the landing site. Following the entry phase, at the start of the descent phase and after deployment of the parachute at about 165 km altitude, all instruments will have direct access to the atmosphere. The objectives are to make detailed in situ measurements of atmospheric structure, composition and dynamics. Images and other remote sensing measurements of the surface will also be made during the descent through the atmosphere. After a descent of about 137 min, the Probe will impact the surface at about 5-6 m/s. As it is hoped that Huygens will survive after impact for at least a few minutes, the payload includes the capability of making in situ measurements for a direct characterisation of the landing site surface. If everything functions nominally, the Probe batteries can provide half an hour or possibly more of electrical energy for an extended surface science phase that would be the bonus of the mission. The current mission scenario foresees the Orbiter listening to the Probe for a full 3 h, which includes at least a 30 min surface phase, as the maximum descent time is expected to be 2.5 h. A surface phase of only a few minutes would allow a quick characterisation of the state and composition of the landing site. An extended surface phase would allow a detailed analysis of a surface sample and meteorological studies of the surface weathering and atmosphere dynamics.

5. Titan

5.1 General characteristics

Titan is the second largest moon of the solar system and it is the only one with a thick atmosphere. That atmosphere was discovered in 1907 by Spanish astronomer José Comas Solá (Comas Solá, 1908), who observed disc edge darkening features and suggested that they were due to an atmosphere, although its existence was not confirmed until 1944 when Gerard Kuiper discovered gaseous methane through spectroscopic observations (Kuiper, 1944). Molecular nitrogen is the major constituent, with the surface pressure 1.5 bar (compared to Earth's 1 bar). Until the mid-1970s, methane was believed to be the major constituent but the Voyager measurements in November 1980 replaced it with N_2, as was already suspected from late 1970s models. The presence of N_2 makes Titan's atmosphere more similar to Earth's than any other solar system body. However, it is much colder: the surface temperature is 94 K and the tropopause temperature is about 70 K at an altitude of 45 km. Other major constituents are CH_4 (a few %) and H_2 (0.2%). It is speculated that argon could also be present in quantities up to 6% (Courtin et al., 1995). The presence of methane makes Titan's atmosphere most interesting.

The photodissociation of CH_4 and N_2 in Titan's atmosphere, driven by solar UV radiation, cosmic rays and precipitating energetic magnetospheric particles, gives rise to a complex organic chemistry. Titan orbits Saturn at 20.3 R_S, which occasionally brings it outside the large Kronian magnetosphere when solar wind pressure pushes the magnetopause inside the orbit. Most of the time, however, Titan is inside Saturn's magnetosphere, which underlines the importance of the energetic electrons as an energy source for its upper atmosphere photochemistry. As a result of this complex photochemistry, the atmosphere also contains ethane, acetylene and more complex hydrocarbon molecules. Chemical reactions in the continuously evolving atmosphere provide possible analogues for the prebiotic chemistry that was at work within the atmosphere of the primitive Earth a few thousand million years ago, before the apparition of life. Titan's atmosphere is too cold for life to evolve in it, but the mission does offer the opportunity to study prebiotic chemistry on a planetary scale (Owen et al., 1997).

The nature of the surface is Titan's main mystery. Like Earth, it could be partially covered by lakes or even oceans, but in this case a mixture of methane and ethane. However, it may be a dry surface, with underground liquid methane reservoirs continuously resupplying the atmosphere's gaseous methane.

Table 1. Physical properties of Titan.

Surface radius	2575±0.5 km
Mass	1.346×10^{23} kg (2.2% M_{Earth})
GM	8978.1 km^3/s^2
Surface gravity	1.345 m/s^2
Mean density	1.881 g/cm^3
Distance from Saturn	1.226×10^6 km (20.3 R_S)
Orbital period	15.95 d
Rotation period	15.95 d
Surface temperature	94 K
Surface pressure	1496±20 mbar

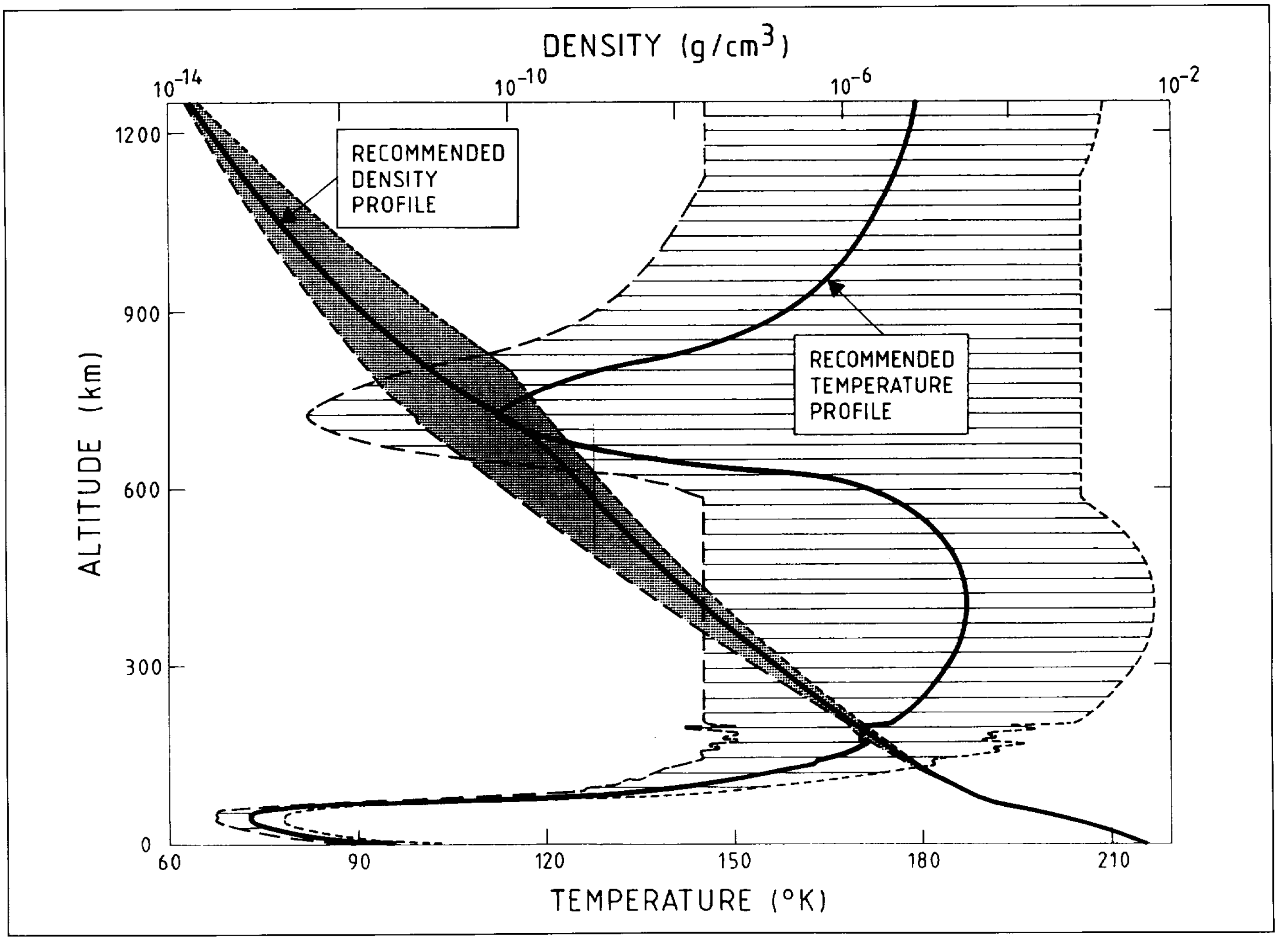
5.2 Physical properties of Titan

The physical properties of Titan are listed in Table 1.

5.3 The Titan atmosphere thermal profile

The most reliable 'engineering' model of Titan's atmosphere was established in 1986 (Lellouch & Hunten, 1987; 1997) during the Phase A study (Fig. 5). Subsequently, an improved 'engineering' model was established (Yelle, 1994; Yelle et al., 1997). This new model did not deviate significantly from the Lellouch-Hunten model in the altitude range of prime concern for Huygens, so the earlier one was retained as the reference model for designing the entry heatshield and the parachute system.

Fig. 5. The Lellouch-Hunten Titan atmosphere model was used as the 'engineering model' for designing the heatshield and parachutes. This model comprises three profiles taking account of all uncertainties in the thermal profile.



5.4 Upper atmosphere composition

The possible presence of argon in Titan's atmosphere has been a major design constraint for the heatshield, as it would significantly contribute to the radiative heat flux during the entry phase. The shield was designed to be compatible with the maximum argon content identified by the Lellouch-Hunten model (21%). The upper limit was subsequently reduced to 14% (Strobel et al., 1993) and then to 6% (Courtin et al., 1995) to the growing satisfaction of the heatshield designers as their performance margin increased.

5.5 Wind model

The presence of a zonal wind will affect the Probe's parachute descent trajectory. A proper estimation of the zonal wind was of paramount importance for designing the Probe-to-Orbiter radio relay link geometry, and hence the Orbiter trajectory during the Probe descent. The wind model used was derived by Flasar et al. (1981; Lunine et al., 1991; Flasar et al., 1997) from the measured latitudinal thermal gradients. This model provides the amplitude of the zonal wind versus altitude, but it cannot predict whether the wind blows west-to-east or east-to-west. Both directions have been assumed to be of equal probability for designing the radio link.

5.6 Other models

Other models were established for designing the Probe. They include:

- the lightning model (Probe susceptibility to lightning);
- the surface radar reflectivity (design of the Probe radar);
- the moist-convection model (Probe icing risk);
- wind gust model (parachute stability);
- gravity wave model (noise on the entry profile);
- S-band signal attenuation in Titan's atmosphere (radio link performance).

All models used for the design on the Probe are thoroughly documented in this volume.

6. The Huygens Payload

The Huygens payload comprises six instruments provided by Principal Investigators. The principal characteristics are listed in Table 2. A brief description of each instrument in turn is provided below; more detailed descriptions are provided in the individual instrument papers in this volume.

6.1 The Gas Chromatograph and Mass Spectrometer (GCMS)

GCMS is a highly versatile gas chemical analyser designed to identify and quantify the abundance of the various atmospheric constituents. It has the capability for analysing argon and other noble gases and for making isotopic measurements. The GCMS inlet system is located near the apex in front of the Probe, where the dynamic pressure drives the gas into the instrument. GCMS works either in the direct mass spectrometer mode, or in the more powerful mode in which the gas sample is passed through gas chromatograph columns to separate components of similar mass before analysis with the mass spectrometer. The instrument is also equipped with gas samplers for filling at high altitude, for later in the descent when more time can be devoted to their analyses. The instrument is equipped with a separate ionisation chamber for analysis of the aerosol pyrolyser products fed by the ACP, the instrument described next. GCMS can also, thanks to its heated inlet, measure the composition of a vaporised surface sample in the event that a safe landing allows the collection and transmission of data for several minutes.

6.2 The Aerosol Collector and Pyrolyser (ACP)

ACP is designed to collect aerosols for GCMS to analyse their chemical compositions. It is equipped with a deployable sampling device that will be operated twice in order to collect the aerosols from two atmospheric layers: the first from the top of the atmosphere down to about 40 km, and the second in the cloud layer from about 23 km down to 17 km. After extension of the sampling device, a pump draws the atmosphere and its aerosols through filters in order to capture the aerosols. At the end of each sampling, the filter is retracted into an oven where the aerosols are heated to three, increasing, temperatures in order to conduct a step pyrolysis. The volatiles are vaporised first at the lowest temperature, then the more complex less volatile organic material, and finally the core of the particles. The pyrolyser products are flushed to GCMS for analysis, thereby providing spectra for each analysis step.

6.3 The Descent Imager/Spectral Radiometer (DISR)

DISR is a multi-sensor optical instrument capable of imaging and making spectral measurements over a wide range of the optical spectrum (UV-IR, 0.3-1.64 μm).

An important feature of Titan is its aerosols and thick atmosphere, where the temperature structure is determined by the radiative and convective heat transport processes. DISR measures the upward and downward heat fluxes. An aureole sensor measures the intensity of the Sun's halo, yielding the degree of sunlight scattering caused primarily by the column density of aerosols along the line of sight. This, in turn, allows deductions on the aerosols' physical properties. DISR is also equipped with a side-looking horizon instrument to image the clouds.

DISR also has the capability for addressing one of Huygens' prime objectives: investigating the nature and composition of the surface. Two cameras (one visible, one IR) looking downwards and sideways image the surface and, as Huygens spins slowly, build up mosaic panoramas. By recording several panoramas during the last part of the descent, it may be possible to infer the Probe's drift (if the surface is not featureless) and contribute to the wind measurements.

Titan is about 10 AU from the Sun, which means the amount of sunlight striking the upper atmosphere is 1/100th of that at Earth. Atmospheric absorption and scattering further reduces the light level at Titan's surface by about a factor of 10. A useful comparison is that Titan's surface brightness is about 350 times that of nighttime on Earth with a Full Moon. While the surface illumination is adequate for imaging, a surface lamp will activate a few hundred metres up to provide enough light in the methane absorption bands for spectral reflectance measurements. These will provide unique information for studying the composition of the surface material.

Evaluation of the gas flow around the Descent Module during the 1 min phase of back cover separation and heatshield release showed there was a small risk of contaminating DISR's optical windows. A cover was later added for safety, it will be ejected shortly after the heatshield is released. Should its release mechanism fail, the cover is provided with optical windows that would still allow measurements with it in place.

6.4 The Huygens Atmosphere Structure Instrument (HASI)

HASI is also a multi-sensor instrument, intended to measure the atmosphere's physical properties, including its electrical properties. Its set of sensors comprises a 3-axis accelerometer, a redundant set of a coarse and a fine temperature sensor, a multi-range pressure sensor and an electric field sensor array.

The set of accelerometers is specifically optimised to measure entry deceleration for inferring the atmosphere thermal profile during the entry phase.

The electric field sensor comprises a relaxation probe to measure the atmosphere's ion conductivity and a quadrupolar array of electrodes for measuring, by using the

Table 2. The principal characteristics of the Huygens payload.

Instrument/PI	*Science objectives*	*Sensors/Measurements*	*Mass (kg)*	*Power (typical/ peak) (W)*	*Energy (during descent) (Wh)*	*Typical data rate (bit/s)*	*Participating Countries*
Huygens Atmospheric Structure Instrument (HASI) M. Fulchignoni, University Paris 7/ Obs. Paris-Meudon (France)	Atmospheric temperature and pressure profile, winds and turbulence. Atmospheric conductivity. Search for lightning. Surface permittivity and radar reflectivity.	*T*: 50-300K, *P*: 0-2000 mbar, γ : 1 μg-20 m*g* AC *E*-field: 0-10 kHz, 80 dB at 2 μV/m Hz$^{1/2}$ DC *E*-field: 50 dB at 40 mV/m Conductivity: 10^{-15} Ω/m to ∞ Relative permittivity: 1 to ∞ Acoustic: 0-5 kHz, 90 dB at 5 mPa	6.3	15/85	38	896	I, A, D, E, F, N, SF,USA, UK, ESA/SSD, IS, PL
Gas Chromatograph Mass Spectrometer (GCMS) H.B. Niemann, NASA/GSFC, Greenbelt (USA)	Atmospheric composition profile. Aerosol pyrolysis products analysis.	Mass range: 2-146 dalton Dynamic range: $>10^8$ Sensitivity: 10^{-10} mixing ratio Mass resolution: 10^{-6} at 60 dalton GC: 3 parallel columns, H_2 carrier gas Quadrupole mass filter 5 electron impact sources Enrichment cells (x100-x1000)	17.3	28/79	115	960	USA, A, F
Aerosol Collector and Pyrolyser (ACP) G.M. Israel, SA/CNRS Verrières-le-Buisson (France)	Aerosol sampling in two layers - pyrolysis and injection to GCMS.	2 samples: 150-40 km, 23-17 km 3-step pyrolysis: 20°C, 250°C, 650°C	6.3	3/85	78	128	F, A, USA
Descent Imager/Spectral Radiometer (DISR) M.G. Tomasko, University of Arizona, Tucson (USA)	Atmosphere composition and cloud structure. Aerosol properties. Atmosphere energy budget. Surface imaging.	Upward and downward visible (480-960 nm) and IR (0.87-1.64 μm) spectrometers, res. 2.4/6.3 nm. Downward and side looking imagers (0.660-1 μm), res. 0.06-0.20° Solar Aureole measurements: 550±5 nm, 939±6 nm. Surface spectral reflectance with surface lamp.	8.1	13/70	42	4800	USA, D, F
Doppler Wind Experiment (DWE) M.K. Bird, University of Bonn (Germany)	Probe Doppler tracking from the Orbiter for zonal wind profile measurement.	(Allan Variance)$^{1/2}$: 10^{-11} (1 s); 5×10^{-12} (10 s); 10^{-12} (100 s) Wind measurements 2-200 m/s Probe spin, signal attenuation	1.9	10/18	28	10	D, I, USA
Surface Science Package (SSP) J.C. Zarnecki University of Kent, Canterbury (UK)	Titan surface state and composition at landing site. Atmospheric measurements.	γ: 0-100 *g*; tilt ±60°; T: 65-110K; T_{th}: 0-400 mW $m^{-1}K^{-1}$ Speed of sound: 150-2000 ms^{-1}, liquid density: 400-700 kg m^{-3} ref. index: 1.25-1.45 Acoustic sounding, liquid relative permittivity	3.9	10/11	30	704	UK, F, USA, ESA/SSD

mutual impedance probe technique, atmosphere permittivity and surface material permittivity after and possibly just before impact, when the Probe is still a few metres above the surface. Two electrodes of the quadrupolar array are also used as an electric antenna to detect atmospheric electromagnetic waves, such as those produced by lightning.

Several of HASI's sensors require accommodation on booms. The temperature and pressure sensors are mounted on a fixed stub, which is long enough to protrude into the free flow. The electrical sensors are mounted on a pair of deployable booms in order to minimise the shielding effects of the Probe body.

The capability for processing the surface-reflected signal of the radar altimeter (the altitude sensor is provided as part of the Probe system, as described later), was added to HASI late in the programme. This additional function allows it to return important information about the surface topography and radar properties below the Probe along its descent track.

6.5 The Doppler Wind Experiment (DWE)

DWE uses one of the two redundant chains of the Probe-Orbiter radio link. It required the addition of two ultra-stable oscillators (USOs) to one chain of the Probe data relay subsystem. The Probe transmitter USO (TUSO) provides a very stable carrier frequency to the Probe-to-Orbiter radio link; the Receiver USO (RUSO) aboard the Orbiter provides an accurate reference signal for Doppler processing of the received carrier signal. The Probe wind drift will induce a measurable Doppler shift in the carrier signal, and that signature will be extracted aboard the Orbiter and merged into the Probe data stream recorded on the Orbiter solid state recorders. It is expected that the Doppler measurements will be so sensitive that, by having the Probe transmit antennas offset from the spin axis by a few cm, the Probe spin rate and spin phase will also be determined. The Probe's swinging motion under the parachute and other radio signal perturbing effects, such as atmospheric attenuation, may also be detectable from the signal.

The chain provided with the TUSO and RUSO is also equipped with the same standard oscillators that equip the other radio relay link chain. Selecting between the DWE USOs (the default configuration) and the standard oscillators will be done during the Probe configuration activity before its release from the Orbiter.

6.6 The Surface Science Package (SSP)

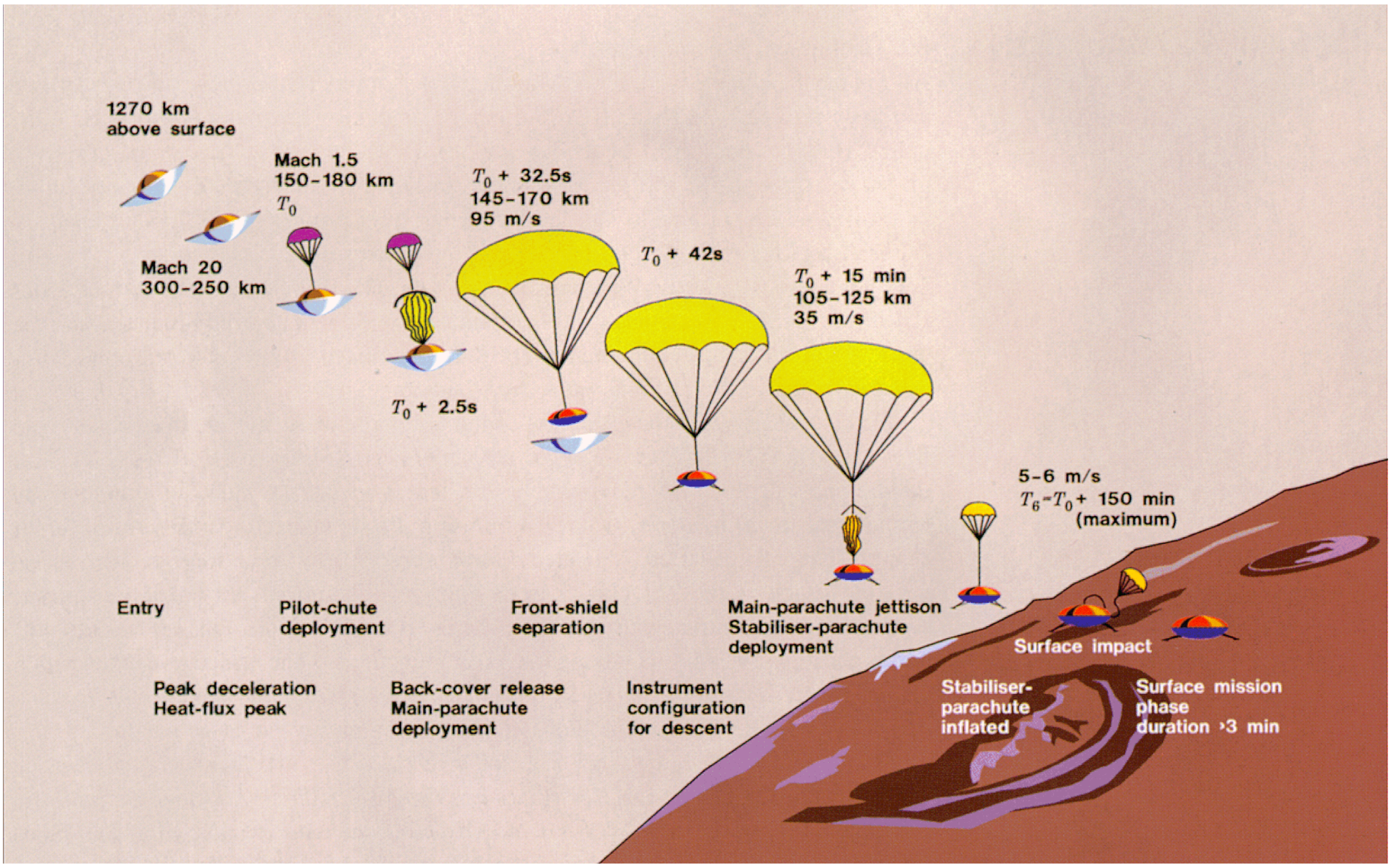
SSP comprises a suite of rather simple sensors for determining the physical properties of the surface at the impact site and for providing unique information on the composition of the surface material. The SSP package includes a force transducer for measuring the impact deceleration, and other sensors to measure the index of refraction, temperature, thermal conductivity, heat capacity, speed of sound and dielectric constant of the (liquid) material at the impact site. The SSP also includes an acoustic sounder for activation a few hundred metres up for sounding the atmosphere's bottom layer and the surface's physical characteristics before impact. If Huygens lands in a liquid, the acoustic sounder will be used in a sonar mode to probe the liquid depth. A tilt sensor is included to indicate the Probe's attitude after impact. Although SSP's objectives are mainly to investigate the surface, several sensors will contribute significantly to the studies of atmospheric properties during the whole descent phase.

7. The Huygens Mission

The Huygens Probe is carried to Titan attached to the Saturn Orbiter as shown in Fig. 3. The Probe is released from the Orbiter after Saturn Orbit Insertion (SOI) during the initial orbit around Saturn, nominally 22 days before Titan encounter, as shown in Fig. 4. Shortly after Probe release, the Orbiter executes a deflection manoeuvre to establish the proper radio communication geometry with Huygens during the Probe's descent phase and also to set the initial conditions for the satellite tour after completion of the Probe mission.

Huygens separates from the Orbiter at 30 cm/s and a spin rate of 7 rpm for stability during the coast and entry phases. The entry subsystem consists of the 2.75 m-diameter front heatshield and the aft cover, both protected against the radiative and convective heat fluxes generated during the entry phase at 350-220 km altitude, where Huygens decelerates from about 6 km/s to 400 m/s (Mach 1.5) in less than 2 min. At Mach 1.5, the parachute deployment sequence initiates, starting with a mortar pulling out a pilot 'chute which, in turn, pulls away the aft cover. After inflation of the 8.3 m diameter main parachute, the front heatshield is released to fall from the Descent Module (DM). Then, after a 30 s delay built into the sequence to ensure that the shield is sufficiently far below the DM to avoid instrument contamination, the GCMS and ACP inlet ports are opened and the HASI booms deployed. The main parachute is sized to pull the DM safely out of the front shield; it is jettisoned after 15 min to avoid a protracted descent and a smaller 2.5 m diameter parachute is deployed. The major events of the entry and descent sequence are illustrated in Fig. 6. The altitude profile is shown in Fig. 7, where the middle curve indicates the nominal profiles and the two other curves define its envelope, taking into account the Lellouch-Hunten atmospheric model uncertainties and all other descent calculation uncertainties. After Huygens separation from the Orbiter, the only energy source is from primary batteries with a total capacity of 1800 Wh. The batteries and all other resources are sized, with a comfortable margin, for a maximum mission duration of 153 min, corresponding to a maximum descent time of 2.5 h and at least 3 min on the surface. Instrument operations are based either

Fig. 6. The Huygens Probe entry and descent sequence.



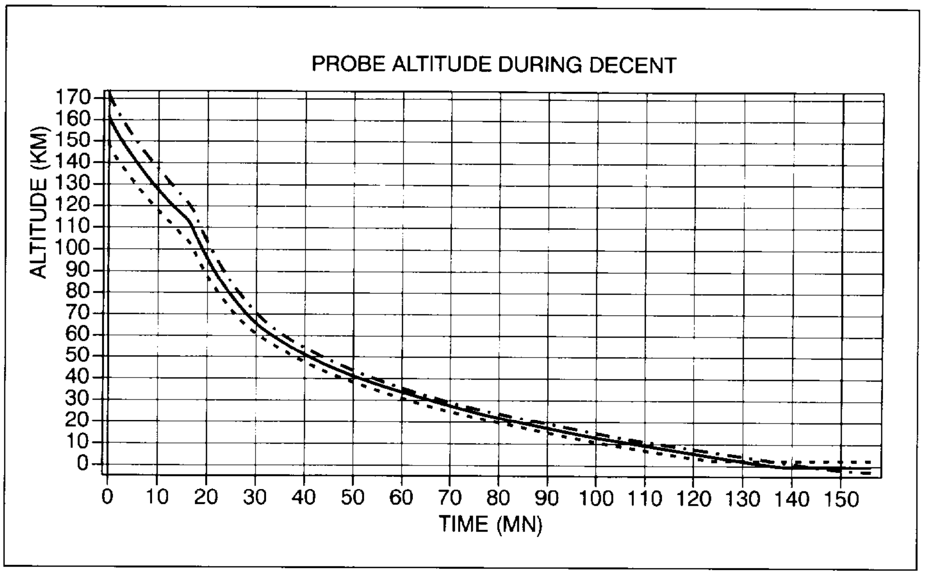


Fig. 7. The altitude descent profile for the three atmosphere profiles of the Lellouch-Hunten model.

on time in the top part of the descent or on measured altitude (from the system-provided radar altimeter) in the bottom part.

Huygens transmits its data at a constant 8 kbit/s to the overflying Orbiter, which points its HGA to a predefined location on Titan for a full 3 h to allow for data reception after landing for 43 min for a nominal descent time of 137 min. The Probe data are stored onboard the Orbiter in the two solid state recorders for later transmission to Earth as soon as the HGA can be redirected after Huygens has completed its mission.

8. Payload Accommodation

8.1 Mechanical accommodation

All the payload elements described above are accommodated on the payload platform as shown in Fig. 8. ACP and GCMS are both single-box instruments with their inlets below Huygens for direct access to the gas flow. Each also has an exhaust tube projecting through the top platform. ACP and GCMS are linked by a temperature-controlled pneumatic line to transfer ACP's pyrolyser products to GCMS for analysis. A serial link between the two instruments synchronises their operations.

DISR consists of two boxes: the Sensor Head (DISR-S) and the Electronics box (DISR-E). DISR-S is mounted on the platform's periphery to accommodate the field of view and scanning requirements. DISR-E is mounted on the platform's inner area and connected to the DISR-S via a short harness.

HASI's sensors, with the exception of the accelerometers, are mounted either on a fixed stub (HASI STUB) or on deployable booms (HASI boom 1 and boom 2). This satisfies post-deployment requirements for access to the gas flow for pressure and temperature measurements, while minimising Probe-induced perturbations to the electric charge distribution at the electric field sensors. The accelerometers are located near the Probe's centre of gravity in its entry configuration. All HASI sensors are connected to the central electronics box (HASI-DPU), which contains the conditioning pre-amplifiers and the central processing functions. The electric antenna pre-amplifiers are housed in two small boxes located as close as possible to the sensors, but still inside the Descent Module, in order to minimise the cable length.

SSP consists of two boxes: the 'Top Hat' structure (SSP-TH) that accommodates all but two of the sensors, and an electronics box (SSP-E). SSP-TH is below the platform, allowing for sensor wetting in case of landing in a liquid. It is connected to SSP-E (on the top of the platform) via a harness through the platform. SSP-TH is also

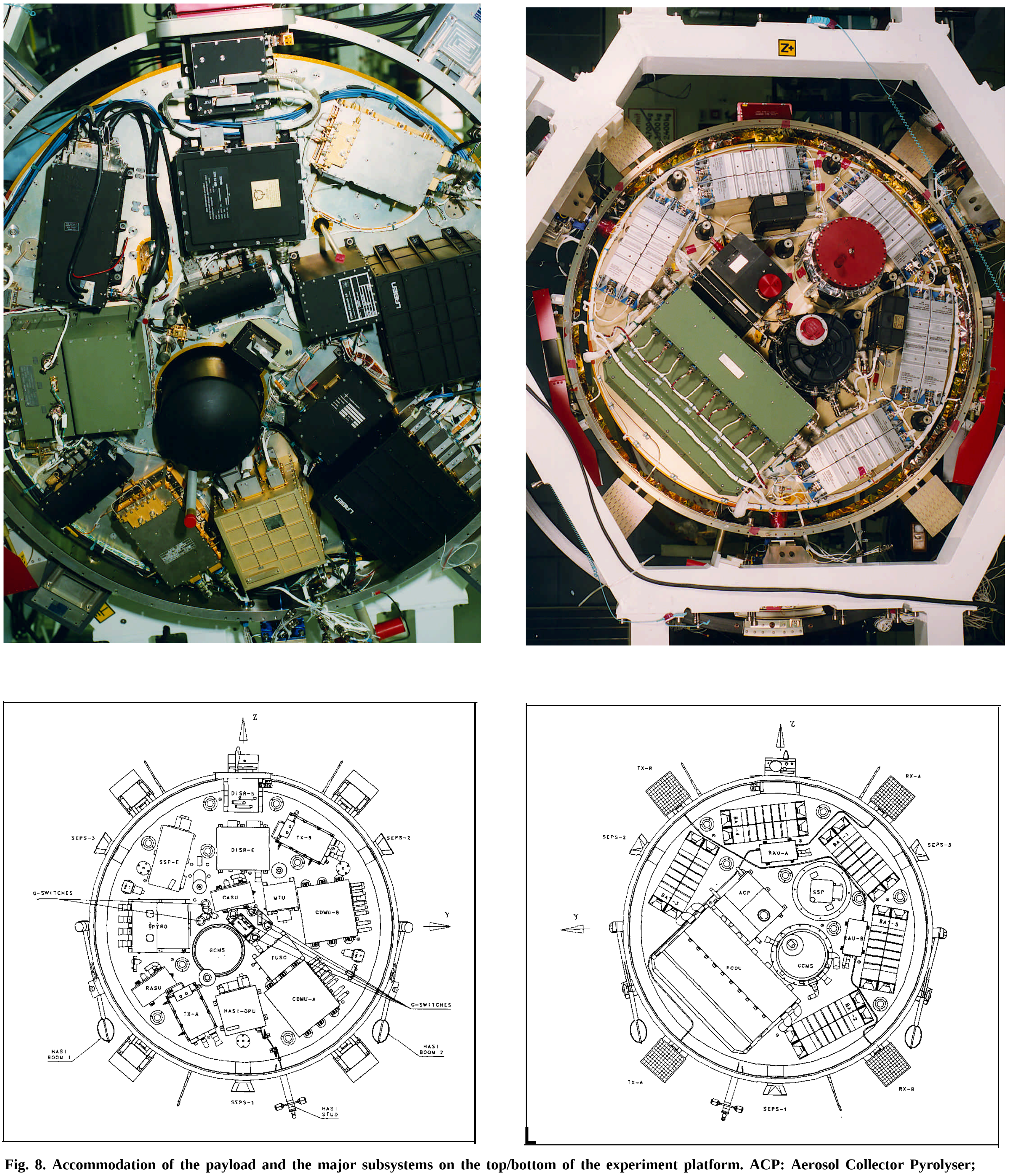


Fig. 8. Accommodation of the payload and the major subsystems on the top/bottom of the experiment platform. ACP: Aerosol Collector Pyrolyser; BAT-l/S: batteries; CASU: Central Acceleration Sensor Unit; CDMU-A/B: Command and Data Management Unit; DISR: Descent Imager/Spectral Radiometer; DISR-E: DISR Electronics box; DISR-S: DISR Sensor Head; GCMS: Gas Chromatograph Mass Spectrometer; HASI: Huygens Atmospheric Structure Instrument; MTU: Mission Timer Unit; PCDU: Power Conditioning and Distribution Unit; PYRO: Pyro Unit; RASU: Radial Acceleration Sensor Unit; RUSO: Receiver Ultra Stable Oscillator; RX-A/B: receive antenna for Radar Altimeter A/B; SEPS: Separation Subsystem; SSP: Surface Science Package; SSP-E: SSP Electronics box; TUSO: Transmitter Ultra Stable Oscillator; TX-A/B: transmit antenna for radar altimeter A/B.

instrumented with a pylon designed for effective transmission of the impact deceleration to the force transducer on the platform. Two sensors are directly mounted on the electronics box: the tilt meter and one of the two accelerometers.

DWE's TUSO is also accommodated on the experiment platform, while RUSO is accommodated in the part of Huygens that remains attached to the Orbiter (Probe Support equipment, PSE).

The overall accommodation of the payload sensors that require direct access to Titan's atmosphere is illustrated in Fig. 9.

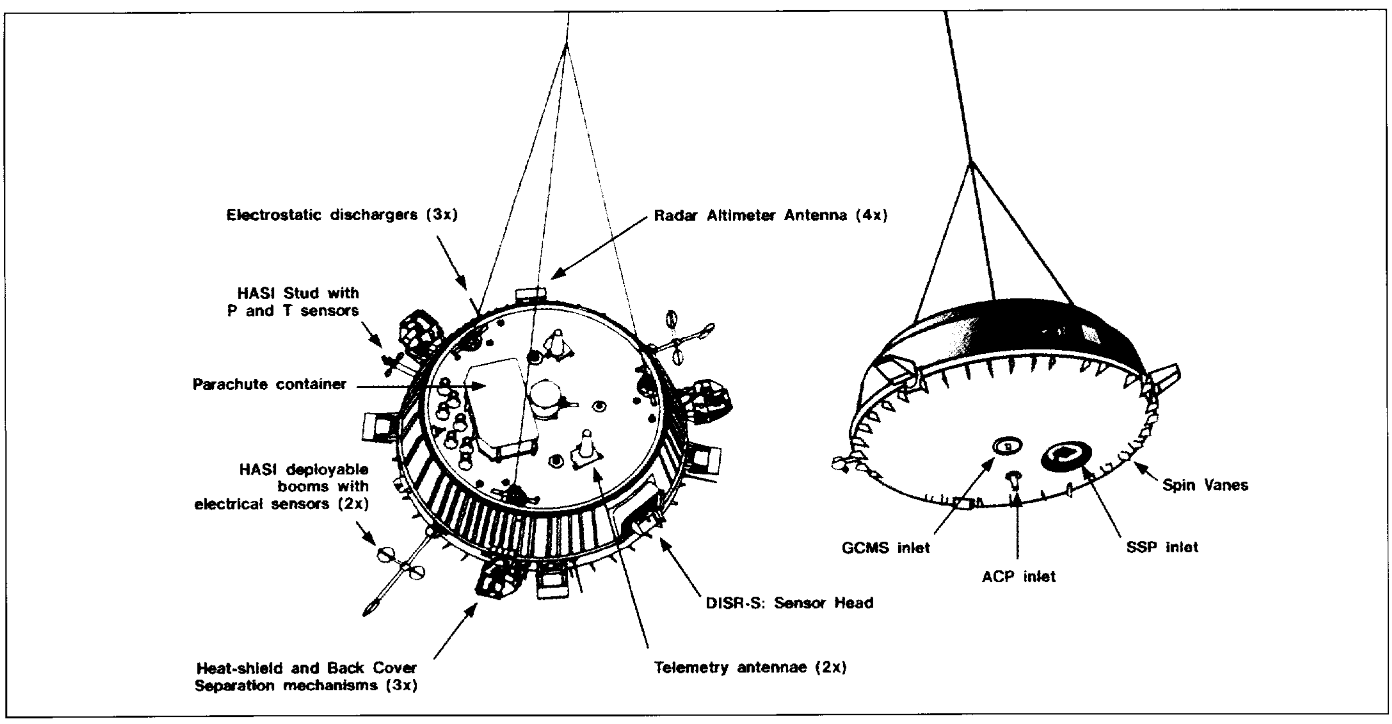
8.2 Probe spin requirements

It is required that Huygens spins during the whole descent to provide the azimuth coverage needed by several sensors. The realtime spin information requirements are imposed by DISR and are very stringent for the final part of the descent for imaging the surface, in order to adapt the time delay between consecutive frames during the mosaic image-taking cycle. The spin is induced by a set of 36 vanes mounted on the bottom part of the foredome. The spin rate is measured by a set a system-provided accelerometers covering 0-15 rpm with an accuracy of 0.1 rpm. The envelope of the expected spin profile is shown in Fig. 10.

8.3 Probe altitude measurements

During the early descent, instrument operations are time-based. However, for maximising the science return, the measurement cycle during the last part of the descent is based on the true altitude. Furthermore, as impact survival is not guaranteed by the Probe's design, maximum science return can be achieved from the last few hundred metres of the descent and possibly for the crucial first few seconds after impact if the altitude is reliably known. In order to satisfy these requirements, the Probe's altitude is measured by a set of two radio altimeters working in the Ku-band (15.3 GHz and 15.7 GHz). The measurements are processed by a sophisticated algorithm in the Probe's central computer that will fall back on the default time-based altitude table in case of a temporary loss of radar lock, e.g. caused by a higher-than-nominal pendulum motion.

Fig. 9. An overall view of the Huygens Probe under its parachute. The HASI booms are deployed and the DISR sensor head can be seen. In the inset, the accommodation of the GCMS, ACP and SSP inlets are shown.



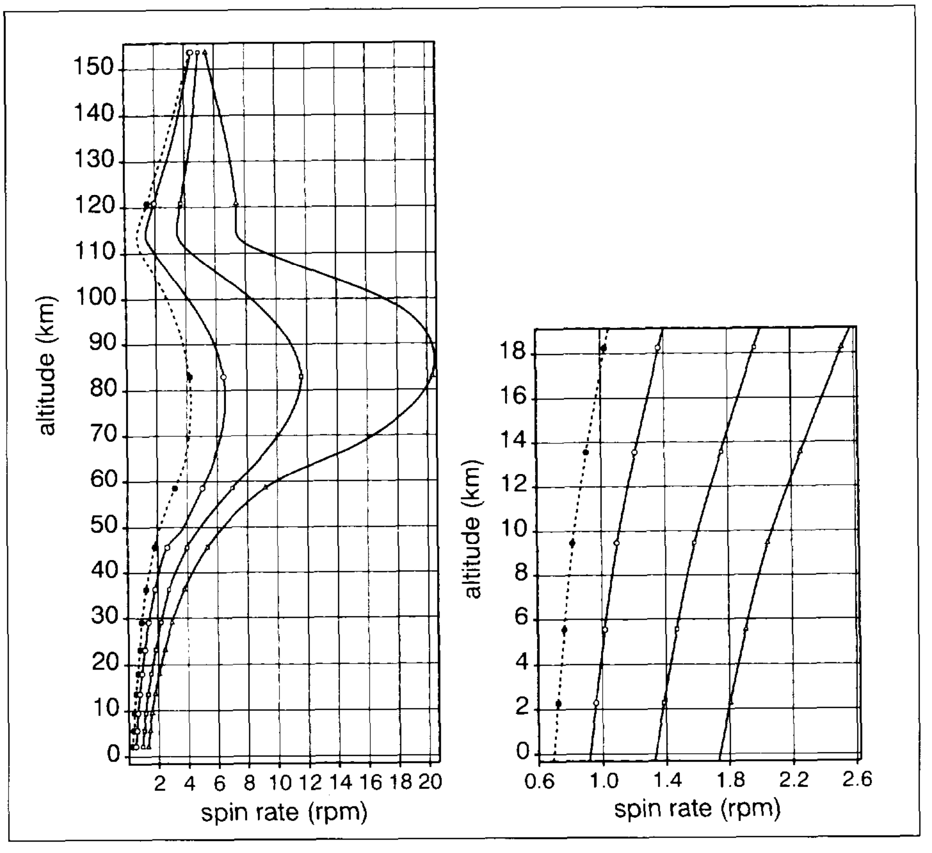


Fig. 10. Envelope of the expected Probe spin altitude profile.

8.4 The Descent Data Broadcast (DDB) pulse

The Probe time, measured spin and processed altitude are broadcast every 2 s to all experiments for their realtime use during descent. The DDB altitude information is used by DISR, HASI and SSP to optimise their measurement cycle.

8.5 Probe targeting requirements

Targeting requirements are imposed by the payload and certain system design aspects, such as the telecommunications geometry and the design of the heatshield ablative material, which are affected by the choice of entry point. DISR and DWE impose demanding requirements on the Sun Zenith Angle (SZA), which should lie within 35-65°, and the maximisation of the zonal wind component along the Probe-Orbiter line of sight. As a result of all the targeting trade-offs, made early during Phase B, an entry angle of −64° was selected. Entry and descent occur over Titan's sunlit hemisphere (Fig. 11). Fig. 12 shows the landing ellipse on images obtained by the Hubble Space Telescope (Smith et al., 1996). It so happens that the landing site is ideally located — Huygens will fly over the region of highest contrast on Titan.

8.6 Entry measurements

Only HASI will perform measurements during the entry phase. These and all data acquired by the other instruments before the Orbiter radio link is established will be buffered within each instrument and interleaved with the realtime data packets that are transmitted by each instrument when the link *is* made.

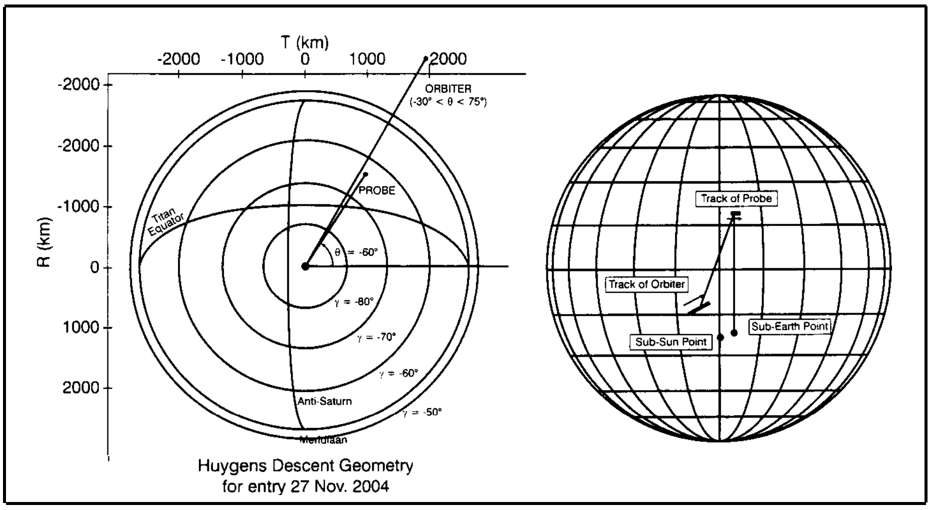


Fig. ll. Probe targeting (B-plane) and entry geometry.

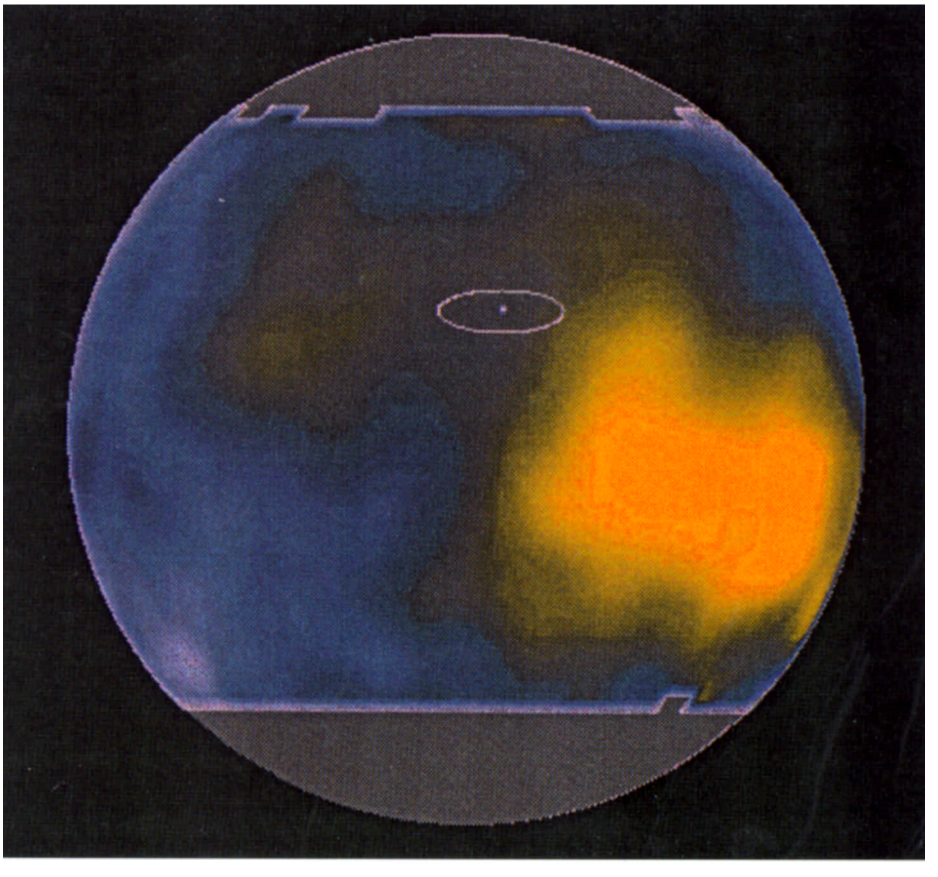


Fig. 12. HST image of Titan with the Huygens 200×1200 km landing ellipse. The entry location was selected before such HST images became available, but it turns out that Huygens will descend over the region of greatest surface contrast. (Courtesy R. Lorenz.)

9. Flight Operations

Huygens operates autonomously after separation from the Orbiter, the radio link to the Orbiter being one-way for telemetry only. Until separation, telecommands can be sent via an umbilical from the Orbiter (which also provides electrical power to the Probe), but this facility will be used only in the cruise and Saturn-orbit phases for monitoring the health of subsystems, maintaining mechanical devices and routinely calibrating the instruments for the biannual checkouts. There will be no scientific measurements before Titan arrival and Huygens will be switched off during most of the cruise. During the 22-day coast phase, after separation from the Orbiter, only a triply-redundant timer will operate to wake up Huygens shortly before the predicted entry into Titan's atmosphere. Loading the value of this timer's duration and depassivation of the batteries that power the Probe after separation will be the last activities initiated by ground command.

Probe operation and the collection of telemetered data are controlled from a dedicated control room, known as the Huygens Probe Operations Centre (HPOC), set up at ESA's European Space Operations Centre (ESOC). Here, command sequences are generated and transferred by dedicated communication lines to the Cassini Mission Support Area (MSA) at the Jet Propulsion Laboratory (JPL), Pasadena, California. There, the Probe sequences are merged with commands to be sent to other subsystems and instruments of the Orbiter for uplink via NASA's Deep Space Network (DSN). Probe telecommands are stored by the Orbiter and forwarded to the Probe Support Equipment (PSE) at specified times (time tags) for immediate execution. As a result of the great distance between Earth and Saturn (requiring up to 160 min for round-trip radio communications), Huygens realtime operations is not possible.

Data collected by the Probe and passed to the PSE via the umbilical (during the attached phase) or the relay link (during the descent phase) are formatted by the PSE and forwarded to the Orbiter's Command and Data Subsystem (CDS). The Orbiter stores the Huygens data in its two solid state recorders for transmission to Earth when the Orbiter is visible from one of the DSN ground stations. From the ground station, the data are forwarded to the MSA where Probe data are separated from other Orbiter data before being stored on the Cassini Project Database (PDB). Operators in the HPOC access the PDB to retrieve Probe data via a Science Operations and Planning Computer, supplied to ESOC by JPL under the terms of the inter-agency agreement.

Subsystem housekeeping data are used by ESOC to monitor Probe performance, while data from the science instruments are extracted for forwarding to the investigators. During the cruise phase, these data are shipped to the scientists' home institutes by CD-ROM (the prime medium) and possibly by public data line. After analysing these data, the investigators meet the operations team to assess the health of the payload and to define the activities for the following checkout period.

During the Saturn-orbit and Probe-mission phases, the investigators are located in HPOC to expedite their access to the data and facilitate interaction with their colleagues and the Probe flight operations team. Accommodation will be provided for the ground support equipment needed to reduce and interpret their data.

10. Data Analysis and Data Archiving

The raw Huygens data will be provided to the Huygens Principal Investigator (PI) teams on CD-ROM after each checkout and for the descent phase. It is the responsibility of each PI team to process the data and to provide a reduced data set to allow a coordinated analysis of the Huygens data set. The Huygens Science Working Team (HSWT) intends to produce a commonly agreed descent profile within weeks of the event to allow all experimenters to analyse their data and interpret their measurements in the most efficient way. A subgroup of the HSWT, the Descent Trajectory Working Group (DTWG), has been set up to optimise the data analysis that should lead to establishing the Probe's descent profile in Titan's atmosphere, providing the optimum means for coordinating analysis of the data from the six instruments.

The initial uncertainty ellipse of the Probe's landing site may be as large as 200×1200 km. HSWT will work in coordination with the Orbiter teams to reduce the uncertainty of the Probe descent trajectory to allow a proper coordinated analysis of the Probe and Orbiter data set and to help plan the observations of the Probe landing site by the Orbiter radar and remote sensing instruments after the Probe mission.

The Huygens data set will be archived as an integral part of the Cassini data archive that is being defined by the Cassini Project Office at JPL. This will provide the optimum approach for synergistic studies using Probe and Orbiter data.

11. The Huygens Science Working Team (HSWT)

The HSWT (Table 3) manages the overall Huygens science activities. It advised the Huygens Project on all science-related matters during the Probe's development phase. During the cruise phase, it will meet periodically to assess the payload's performance and to prepare itself for the Huygens mission and data analysis phase. Activities will peak during the Huygens mission phase, as it coordinates the analysis and interpretation of the Probe data. It will also play an important role in planning the post-Huygens observations of Titan by the Orbiter, and it will participate in joint Probe/Orbiter investigations data analysis and interpretation studies.

Table 3. The Huygens Science Working Team

Chairman: J.-P. Lebreton, ESA/ESTEC, Huygens Project Scientist
Vice-chairman: D. Matson, NASA/JPL, Cassini Project Scientist

PI/DWE: M. Bird, Univ. of Bonn, Germany
PI/HASI: M. Fulchignoni, Univ. Paris 7/Obs. Paris-Meudon, France
IDS/Aeronomy of Titan: D. Gautier, Obs. Paris-Meudon, France
PI/ACP: G. Israel, CNRS/SA, Verrières-le-Buisson, France
IDS/Titan Atmosphere-Surface Interaction: J. Lunine, Univ. of Arizona, USA
PI/GCMS: H. Niemann, NASA Goddard, USA
IDS/Titan Organic Chemistry & Exobiology: F. Raulin, LISA, Univ. Paris 12, France
PI/DISR: M. Tomasko, Univ. of Arizona, USA
PI/SSP: J. Zarnecki, Univ. of Kent at Canterbury, UK

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